LCA Case Studies

Life Cycle Assessment of Tractors

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Abstract. This study was intended to evaluate the environmental impact, and potential improvements for a typical tractor model (LT360D) of LG Machinery Co., Ltd. The life cycle of this study includes all stages from raw material acquisition up to final disposal. The eco-indicator 95 method was employed to perform an impact assessment. The result of this study is expected to represent the environmental feature of typical diesel vehicles at each life cycle stage. This study is a starting point of building life cycle inventories for typical off-road diesel tractors. With this result, environmental weak points of the tractor have been defined, and major improvement strategies have been set up to develop the 'Green Tractor'.

Keywords: Case studies; design for environment (DfE); DfE; eco-indicator 95; LCA; Life Cycle Assessment; product LCA; tractors

Introduction

Due to the need for sustainable development in a global society, great efforts are being made to increase environmental performance and resource efficiency in industrial companies all over the world. Over the last few years, greater attention has been given to the environmental performance and resource efficiency of industrial products [1]. In this product-oriented approach, the whole product system should be considered from "cradle to grave", i.e. from raw material acquisition to final waste treatment of end products. Life Cycle Assessment (LCA) has been conducted as a means of dealing with these issues.

Product Life Cycle Assessment has been developed over the last two decades by a number of different authors. In general, the early development concentrated on beverage containers. It is only in recent years that the LCAs of other product groups have become common [2]. Among those product groups, the automobile industry has started LCA activities since the end of the 1980's [3]. LCAs on automobiles deal with various kinds of items such as a complete car, instrument panel, tire, laminates, fuel consumption, alternative fuel and fuel tank. Based on LCA results, there are a lot of efforts to improve environmental performance of vehicles through their life cycle stages.

Until now agricultural machinery has been given little attention in view of environmental impact compared with a passenger car. Due to heavy weight and fuel use, agricultural machinery is supposed to make considerable environmental impact throughout the life cycle. A tractor was selected for this study because it represents ordinary agricultural machinery. Most tractors are operated with diesel engine. Their functions vary from grinding to excavating in accordance with attachments such as a rotary. The result of this study is a projection of the environmental characteristics of typical off-road, diesel agricultural machinery.

This study was performed as a part of developing a 'Green Tractor' in LG Machinery, following the ISO 14040's standard procedure [4].

1 Goal and Scope Definition

The objective of this study is to identify the environmental feature of the tractor and provide basic information for Design for Environment (DfE). The result of this study will be used to develop an environment-conscious agricultural machinery. Intended audiences are tractor designers in LG Machinery.

2 Function and Functional Unit

The main function of the tractor is preparing soil for cultivation attached with various tools like a rotary. The functional unit of this study is one set of a typical tractor (model: LT360D) produced in LG Machinery which cultivates about 92 ha of land for its entire life span (8 years). Data on area and life span were quoted from the statistics of the NAMRI (National Agricultural Mechanization Research Institute, Korea). Fuel consumption of the tractor strongly depends on soil type and working mode. The average amount - about 8.24 liters per working hour - was taken from statistical data [5].

3 System Boundary

The life cycle of all the system components were investigated from the extraction of raw materials up to final disposal. Environmental data evaluated includes the amount of input materials, energy consumption, solid waste generation, and air/water pollutant release. Electricity supply processes are described with Korean grid mix data. The

Table 1: The system boundary and data collection methods for tractor LCA

Life cycle stage		Data collection method
Material acquisition		SimaPro 4.0 DB 1) PRe 4 2) BUWAL250 3) IDEMAT 96
Manufacturing	Suppliers	Questionnaire: data managed by suppliers
	In-house	1) Direct measuring 2) Data managed by LG Machinery
Transportation		Data managed by LG Machinery
Utilization		1) Data managed by engine manufacturer 2) Data managed by LG Machinery 3) Data from nation-wide statistics
Disposal		Determination of recycling/landfill/incineration ratio with nation-wide statistics

system boundary and data collection methods are shown in **Table 1**.

Manufacturing stage is divided again into two stages: manufacturing by suppliers and in-house manufacturing. The in-house process includes four distinct processes – FMS (Flexible Manufacturing System), transmission assembling, painting and the main assembly process. Not all the manufacturing processes by suppliers are taken into account, but several important processes and modules such as painting, battery and tire manufacturing processes are included.

A cut-off method was used as an allocation method. This method allocates environmental impacts caused by primary material production in proportion to the amount of primary material in the product and it allocates environmental impacts caused by waste management in proportion to the amount of material lost from the technosphere to the environment [6]. The allocation of environmental impacts caused by recycling processes depends on how the boundary between the life cycles is defined. The boundary is defined here so that environmental impacts or benefits from recycling of the tractor are not included in the boundary of this study but are carried over to the next product system which will utilize the recycled material from the tractor. Instead, if the tractor contains some recycled materials, the impacts or benefits from the recycling process of these materials are described in the boundary of this study. Hence, two-fold counting of the recycling effect can be avoided.

4 Inventory Analysis

Representative inventories are represented in **Table 2**, which are composed of major input/output materials and energy used. The most dominant materials of the tractor are iron and steel. They make up to nearly 85% in mass. Life cycle inventory of POSCO (Pohang Iron and Steel Co., Ltd) – the largest steel manufacturer in Korea – data was used in order to minimize the error from using an inappropriate database [7]. Korean grid mix was examined to constitute a suitable database for electricity that reflects the real condition in

Table 2: Result of inventory analysis

		Unit	Raw material	Supplier	In-house	Transport	Use	Dispose
Input Material	Bauxite	kg	63.8	0.523	0.0009	0	0	0.71
	Coal	kg	907.3	109.6	160.2	0	0	253.6
	Crude oil	kg	194.4	73.2	50.0	26.2	11500	7.02
	Iron (in ore)	kg	2274.8	0.067	0	0	0	3.23
	Limestone	kg	-323.6	0.008	0.0013	0	0	0.15
Primary energy		MJ	44514	14400	10971	1220	535000	24000
Air emission	CO_2	kg	3130	766	537	402	40503	1060
	NOx	kg	4.4	5.4	1.2	1.5	349	2.6
	Hydrocarbon	kg	21.7	0.021		0.40	89.6	0.13
	CO	kg	50.2	1.38	0.12	0.34	45.3	0.36
	Dust	kg	0.6	0.005	0.60	0.1	19.5	0.03
Water emission	BOD	g	107	1.58	0.234	0.157	895	0.61
	N-tot	g	48.2	9.88	2.5	0	2.18	9.15

Korea [8]. For other inventories than iron, steel and electricity, commercial databases such as PRe4, BUWAL250 and IDEMAT96 were employed without modification.

About 85% of primary energy is consumed at a use phase. The amount of diesel oil used during the life of the tractor is over 11 tons, which contains nearly all the primary energy consumed. Iron and steel parts make the greatest contribution in proportion to the mass ratio (about 67%) to primary energy consumption at the raw material acquisition stage. The materials produced through energy intensive processes like aluminum or SBR (Styrene Butadiene Rubber) show considerable value of primary energy consumption. Generally, carbon dioxide emission is determined by the amount of energy consumption, which makes the use stage the most dominant in carbon dioxide emission.

Almost all NO_x emission is generated during the use stage. NO_x is one of the main emissions that cause a great impact on the environment. Diesel engine operation involves the emission of NO_x, CO and particulate matters (PM), and these are regulated by the EPA from 1999. NOx is also emitted during the component manufacturing stage. The casting process takes the largest responsibility for this.

Such items as process energy, emission during process and auxiliary materials were analyzed at an in-house manufacturing stage. The influence by process energy is dominant for there is no process that involves a lot of emissions or uses toxic material except the painting process where some solvents are emitted.

The disposal stage consists of recycling, landfill and incineration. Since there was no available data about the disposal stage for tractors, the statistics on disposal of wastes – the proportion of recycling, landfill and incineration of materials – in Korea were applied (→*Table 3*) [9]. Lacking database, a lot of energy consumed at this stage involves the recycling of materials and most of the inventories for landfill and incineration are excluded.

Table 3: Recycle, landfill and incineration ratio of wastes in Korea

	iron/steel	tire	plastic	lubricant
Recycle(%)	100	89.1	16.1	74.8
Landfill(%)	0	10.1	77.8	0
Incineration(%)	0	0.08	6.1	25.2

5 Impact Assessment

The inventory data above was converted into environmental impact using the Eco-indicator 95 method [10]. Normalization factor data was taken from several Korean [11,12] and European weight factors between categories and was applied without any modifications [10].

The relative magnitude of environmental impacts among stages converted into Eco-indicators appears in **Fig. 1**. The impacts were classified into several environmental categories in Fig. 2. The impact on acidification at use stage turns out to be the most serious. There were also substantial impacts on eutrophication, summer and winter smog and green house effects. NOx emission at the use stage is responsible for both acidification and eutrophication.

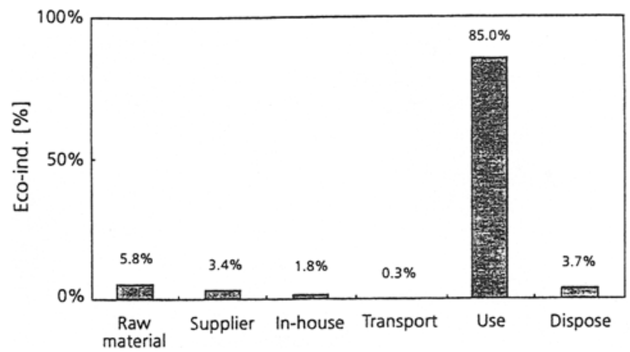

Fig. 1: Result of impact assessment

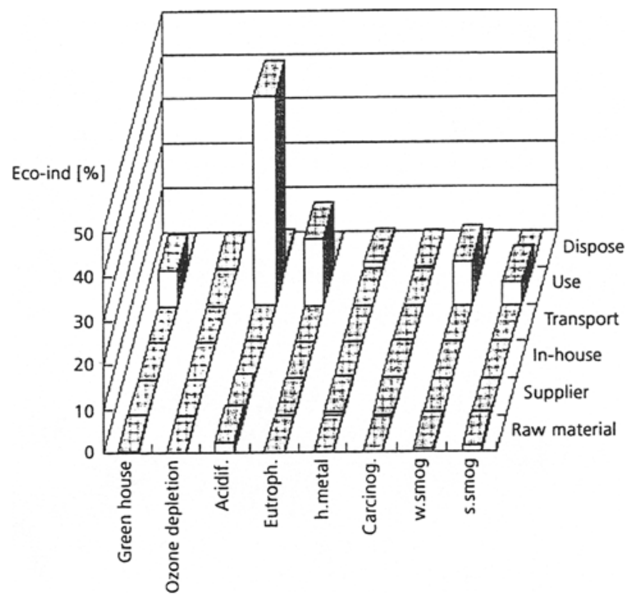

Fig. 2: Impact for each environmental category

6 Discussion

Based on the impact assessment results, the major contributors at each stage were identified. Most environmental impacts occur at the use stage owing to the emissions from diesel engine operation, e.g. from NO_x or CO. The life cycle of the tractor has the most serious impacts on acidification, which is mainly due to these emissions. It also has considerable influence on eutrophication and summer smog. According to many LCA studies on products such as appliances or vehicles, it turned out that the use stage tends to be the most influential due to the continuous use of energy or materials. Several LCA case studies on the automobile showed that the use stage surpasses the other stages in terms of environmental burden. One example is the results of an LCI study on gasoline passenger cars. In terms of the energy consumption and CO_2 emissions of one passenger car, without part changes due to accidents, the running stage exceeds 80% of the whole [13].

Tractors have many things in common with automobiles. However, there exist some dissimilarities between the LCA result on the automobile and the tractor arising from the different engine systems. All the current tractors are operated with diesel engine while automobiles run with gasoline engine. Generally, a diesel engine has great impacts on the environment due to its emission into the atmosphere including NO_x, CO, hydrocarbons and PM [14].

The material acquisition stage follows next due to large amount of various constituent materials. The total weight of the tractor is up to about 1.7 tons, without optional equipment. However, it was found that the relative portion of the material acquisition stage in impact is much less than that of the use stage, even though its absolute value is not negligible.

7 Conclusion

The above result is expected to be linked to design for environment (DfE) in an effective manner. Using LCA results, priorities for environmental improvement can be set. In this study, the way to go is apparently to reduce air emission during operation and material use. With this result, 2 major strategies were defined. One is to adopt a green engine, the other is to lessen material use. It is true that other environmental impact should not be neglected only because they have relatively low environmental impact in the life cycle stage. However, it will be more fruitful to concentrate on major weak points, and then to shift to the next weak points.

Green engine means the engine that consumes less fuel or emits little pollutants. As the environmental impact at the use stage is much larger than at any other stage, the whole impact throughout the life cycle can be reduced in a large amount by using a green engine. Basically, LG machinery merely assembles major components such as engine, transmission, chassis, etc. Most of the environmental effects of a tractor are due from those parts from foreign and domestic suppliers. Presently, supplier management is concentrated on cost and functional parts. In the assembly industry, selecting more environment-friendly suppliers is a key to reducing the whole life cycle impact. LG machinery are trying to reduce environment impact at the use stage by requiring suppliers to submit engine emission data or performing self tests of engine emission.

Reducing the weight of the tractor would also be helpful considering the impact at the material acquisition stage. Currently, tractors make use of a large amount of ferro-metals for safety and workability. Lightweight tractors are advantageous for reducing fuel use as well as economizing the material use. However, it is important to lessen the weight of the tractor without deteriorating its original function. The weight of some controllable parts were reduced through idea meetings and workshops.

There is still on-going effort to reduce the environmental impact by further reducing material use, adopting most appropriate engines, and improving other process such as painting and washing for tractor parts. LCA will provide information on the current status and the result of improvement through these DfE activities.

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